SMART GRID INTEROPERABILITY PANEL

Local Grid Definitions

A white paper, developed by the Smart Grid Interoperability Panel, Home Building and Industrial Working Group

February 25, 2016

Document Source: Lawrence Berkeley National Laboratory
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Production Date: February 25, 2016

 This work was performed under the financial assistance award 70NANB16H002 from the U.S Department of Commerce, National Institute of Standards and Technology.

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The Smart Grid Interoperability Panel (SGIP) is an industry consortium representing a cross section of the energy ecosystem focusing on accelerating grid modernization and the energy internet of things through policy, education, and promotion of interoperability and standards to empower customers and enable a sustainable energy future. Our members are utilities, vendors, investment institutions, industry associations, regulators, government entities, national labs, services providers and universities. A nonprofit organization, we drive change through a consensus process. Visit www.sgip.org.

Acknowledgements

Many thanks to Chris Marnay for his inspiration and assistance. Also helpful have been Ken Christensen, David Katz, Dane Christensen, Ken Wacks, Dean Cooper, and others.

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1 Introduction

"Local grids" — microgrids and nanogrids — is a topic of increasing interest, but the core terms are usually used with ambiguous and conflicting definitions, or none at all. This lack of clarity impedes discussions and progress towards establishing good policy and creating needed technology, such as interoperability standards. Clarity and consistency in definitions can give insight to grid architectures, technology directions, and policies. This paper reviews key terms and definitions related to power distribution infrastructures in buildings (or campuses) that enable some local grid functionality; "local grid" is taken to be an infrastructure separate from that operated by electric utilities. This paper makes recommendations about which definitions are preferable. It also includes a discussion about the merits and limitations of existing and alternate definitions.

2 Recommendations

Microgrid: "An electricity distribution system containing loads and distributed energy resources (such as generators, storage devices, or loads) that can be operated in a controlled, coordinated way while islanded from any utility grid, and is under the control of a single management entity." (Adapted from CIGRÉ)

Nanogrid: "A single domain of power; single physical layer of power distribution, reliability, quality, capacity, price, and administration." (Nordman, 2013)

Picogrid: "An individual device with its own internal battery for operation when external sources are not available or not preferred, and managed use of the battery." (Adapted from Ghai et al. 2013)

The following terms are useful in discussions of local grids, but are not recommended for formal definition at this time, pending further consideration and discussion.

Power distribution: Technology / infrastructure that moves electrons from devices where they are available to devices where they are wanted.

Local grid: A microgrid, nanogrid, or picogrid.

Milligrid: A portion of a utility's infrastructure that can operate independently of the rest of the utility grid.

Minigrid: A utility grid that is small in electrical capacity and geography.

3 Discussion

The remainder of this paper reviews existing relevant definitions for these terms and comments on their implications, merit, and application. With two exceptions, this paper covers only terms for systems that are internal to a single building or campus of adjacent buildings — a single "management entity." This limitation in scope of geography and in management is encompassed by the general term of "local grid," in contrast to "utility grid" with customers distinct from the entity that manages the grid, and usually involves regulation of rates, reliability, and access. Utility grids usually cover a wide geographical extent and multiple (usually very many) customers, but it is the customer relationship and usual presence of a regulatory context that is the defining characteristic.

For most key terms, there is at least a rough consensus on definitions and applications (as indicated by usage in reports). The exception is nanogrid, for which there are several definitions in play; these indicate different technology directions and likely outcomes. Sources for terms are **bolded**.

3.1 Power Distribution

A basic function of any grid is to balance supply and demand, and to move power among generation, storage, end-use devices, and exchange power with any connected adjacent grids. This has been defined as the "Technology / infrastructure that moves electrons from devices where they are available to devices where they are wanted" (Nordman, 2013)**.** Power distribution technologies can include, or not include, communication about power. This term does not have divergent definitions (usually it is not defined at all), but as a core function of a grid it merits a more formal definition.

3.2 Local Grid

A local grid is a microgrid or nanogrid. This is not defined formally at present, but is a power distribution system of limited management scope (and so geography). For this reason, a "utility microgrid" is not a local grid, making the use of the word 'microgrid' in that term awkward and undesirable. A "utility grid" is inherently a local[1] monopoly, so that the issue of management domains and regulation is fundamental to utility grids. That local grids are not encumbered by regulation or complications from multiple management domains is fundamental to what they are.

3.3 Microgrid

"A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode." (Department of Energy (DOE) Microgrid Exchange Group[2])

"Microgrids are electricity distribution systems containing loads and DER, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded." (CIGRÉ C6.22 Working Group).

1 "Local" has different meaning here from that in the term "local grid." Utilities are local monopolies at city

2 https://building-microgrid.lbl.gov/microgrid-definitions

Both of these definitions — from the U.S. Department of Energy (**DOE**) and the International Council of Large Electric Systems (**CIGRÉ**) — focus on the ability to island from a utility grid (operate independently). For the most part these definitions are not substantively different, and quite unfortunately both definitions seem to exclude systems that never connect to a utility grid (though the DOE definition is clearer on this point). As there is no compelling reason to exclude systems that are always off-grid, a new definition is needed.

A notable feature of both definitions is that no minimum or maximum electrical capacity is specified. Thus, a simple notebook computer with a battery would be a microgrid, and certainly a house would qualify if it can operate on its own. Nevertheless, common understanding of microgrids is centered on larger buildings or campuses, as that is where they are most commonly found today. While not part of either definition, microgrids generally cover infrastructure from only one management entity; this aspect is also needed.

Thus, the CIGRÉ definition could be adapted with these considerations in mind as below. Added text is bolded and indications are given where text is deleted. The definition was also made singular (from plural) to match the others.

*"**A** microgrid **is an** electricity distribution system containing loads and **distributed energy resources** […] (such as […] generators, storage devices, or […] loads) that can be operated in a controlled, coordinated way while […] islanded […] **from any** utility **grid, and is under the control of a single management entity**."*

This does bring up the issue of what a multi-tenant building is that can operate independently from a standard utility grid. If each tenant can operate independently as well, then it is a network of microgrids. If tenants cannot operate independently, then it may best be considered a minigrid (see below).

The key attribute of a microgrid is **capability**.

3.4 Picogrid

In parts of the world where utility grid power is much less reliable than in the U.S. and Europe, more attention is given to reliability at all scales. This led to the development of a definition for a picogrid, in which a single device can be independent for power, at least for a time. A definition of this can be:

> "An individual device with its own internal battery for operation when external sources are not available or not preferred, and managed use of the battery" (Adapted from Ghai et al. 2013).

Picogrids are in widespread today, as with notebook PCs, phones, and most wireless speakers. This definition seems uncontroversial, and is a suitable and welcome complement to microgrid and nanogrid.

The key attribute of a picogrid is **singularity**.

3.5 Nanogrid

The need for a term such as nanogrid became clear because it was useful for describing an electrical infrastructure with less extent than the term "microgrid" implies. While 'extent' is commonly assumed to be electrical capacity, it can refer to other aspects, such as reduced capability or complexity from what a microgrid can imply. The term is often used without reference to a particular definition, with the general intent to refer to a "small microgrid," possibly using DC. In addition, there are at least four distinct approaches to defining a nanogrid, as follows. The recommended definition is from the concept of Local Power Distribution (**LPD**; Nordman and Christensen, 2015a,b):

A single domain of power; single voltage, frequency (if AC), reliability, quality, capacity (power), price, and administration. Storage is internal to a nanogrid. Generation forms its own nanogrid.

This should be simplified and clarified (for reasons noted below as:

A single domain of power; single physical layer of power distribution, reliability, quality, capacity, price, and administration.

The key attribute of a nanogrid is **simplicity.**

The LPD definition emphasizes simplicity, and introduces the idea of a local price (paraphrased from Nordman, 2012; concept dates to 2010). It is part of the broader concept of Local Power Distribution, which covers networks of nanogrids connecting end-use devices, local generation, with a microgrid controller at any utility grid interface.

Because a circuit breaker introduces a capacity constraint and reliability control, in principle each circuit is a separate nanogrid, as is anything downstream of a transformer. These distinctions are true but often not that useful to make.

Nanogrids are more useful in the context of DC power in which the defining factors are usually much different from any AC system to which they are connected. A shortcoming of this definition is that it doesn't take into account technologies that allow the negotiation of different voltages between a supplying and consuming device (examples include USB and UPAMD). Thus, voltage and frequency could be more usefully characterized as a single physical layer of power distribution, as defined by some technology standard.

A notebook PC is a clear example of a nanogrid, in that it can distribute power to attached USB devices.

3.6 Other Nanogrid Definitions (references at end)

3.6.1 Bryan et al.

A small isolated DC power system that uses distributed renewable energy sources in conjunction with storage to supply continuous power to small local loads.

The Bryan definition (Bryan et al, 2002) is narrow in prescribing size, only using DC, and never grid-connected. Isolated DC systems are common, as in all cars and trucks. Specifying "small" without a numeric limit is awkward since small in one context is large in another. It seems unnecessary to limit nanogrids to being only DC, never grid connected, and only using renewable generation. These seem more about how the grid architecture is used in particular contexts, not what the architecture fundamentally is.

<u>Navigant</u>

A small electrical domain

- *connected to the grid of no greater than 100 kW and limited to a single building structure or primary load or*
- *a network of off-grid loads not exceeding 5 kW;*

both categories representing devices capable of islanding and/or energy self-sufficiency through some level of intelligent DER management or controls

Navigant Consulting (2013; formatting added) defines a nanogrid with respect to electrical capacity and spatial extent or being never utility-grid connected. This is the only nanogrid definition with an explicit electrical capacity constraint. It is awkward to cover two mutually exclusive categories of electrical system within the same domain; having a single term for each of these would be better. Also difficult is including "single building" which doesn't have a clear application to many circumstances.

3.6.2 Houseman et al.

A single building housing a single family or business that has some load and some generation capability with or without storage, that can adjust the load to some extent to deal with the available local supply and can in an emergency sustain some generation to support critical loads.

This last definition of the term means essentially a small microgrid, though what "small" means is not specified. The limitations on building type and size seem unnecessary, and the additional capabilities that are required or prohibited are ambiguous. Nevertheless, this text (from Doug Houseman of EnerNex) reflects contemporary usage by a number of people and was not intended to be a formal definition as-is.

Comparison among Nanogrid Definitions

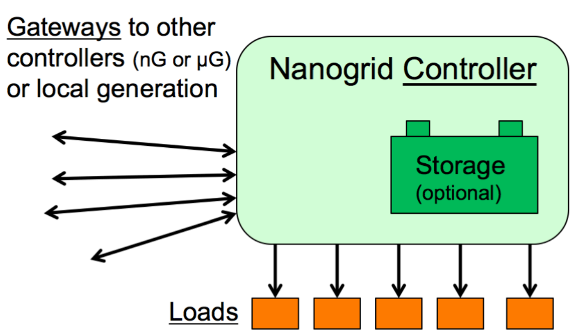
The definitions of nanogrid above embody a variety of characteristics, as shown in Table 1. Only one characteristic (presence of electricity storage) is covered by all definitions. No definition covers all characteristics explicitly. All definitions except LPD apply a scale limitation that is absent in the associated definitions of microgrid and picogrid.

Characteristic	LPD	Bryan	Navigant	Houseman
DC-only		Yes		
Never grid-connected		Yes	Some	
Small		Yes	Some	Yes
Explicit capacity limit		Implied	Yes	Implied
Only renewable generation		Yes		
Storage required	Some	Yes	Some	Some
Simple	Yes			
Communications about power	Yes			
Only single building			Some	Yes
Grid-connected	Some		Some	Yes
Off-grid capability limited				Yes

Table 1. Characteristics of "Nanogrid" from different definitions

Nanogrids in context of Local Power Distribution

Figure 1. Schematic of a Nanogrid
(Source; Nordman & Christensen, 2015)



This paper recommends an adaptation of the LPD definition (since that was developed by the author of this paper, this not surprising).

The LPD nanogrid definition is unique among the four in that it is not a stand-alone concept, but is part of a larger system, which within it has a generic wiring topology, as shown in Figure 1. None of the other definitions is specific enough to lead to any conclusion about implications for wiring topologies. Some further details of LPD Nanogrid are that they:

- Are the smallest unit of power distribution (not divisible);
- Encompass a single physical layer (voltage; usually DC);
- Are a single domain: administration, reliability, quality, and price;
- Can interoperate with other local grids through gateways.
- Could cover a wide range in technology, capability, and capacity; and
- Enable a network model of power – "Local Power Distribution"

In addition, generation forms own nanogrid and in a fully-functioning nanogrid, all links include communications.

> The expected LPD deployment pattern is for an individual building to contain a few too many nanogrids, which may be composed of different physical layers (e.g. some AC and some DC; some USB, some Ethernet; etc.), and which are networked to each other.

3.6.3 Utility Microgrid

A "utility microgrid" generally refers to a portion of a utility infrastructure that can operate independently of the rest of the utility grid, with the scale usually a few, to a few hundred, buildings. Some local generation (or at least local storage) is required as part of the utility infrastructure. This is also called a "milligrid," "Utility Distribution Microgrid," or "Community Microgrid" (Marnay et al., 2011 and 2012). As noted above, it is awkward to use the word "microgrid" as part of this term as that refers to infrastructure that is all part of a single management domain, and hence not covering utility infrastructure. For this reason, the term "milligrid" is preferred. This paper does not offer a formal definition.

3.6.4 Minigrid

The topic of "energy access" covers how to provide adequate electricity services to people who today have little or no electricity. The largest number of such people is in Africa, India, and other parts of Asia (particularly island communities as in the Philippines and Indonesia). Energy access spans the range from bringing traditional utility grid technology to households and businesses that lack it today, to stand-alone devices or single-building systems. In between lies the notion of a "minigrid" (often hyphenated[3]), which is like a traditional utility grid but with limited scope of geography and capacity. Unfortunately, the term is almost never defined. People generally agree on what is in or out of the "minigrids" category, but as their range in electrical capacity, geographical extent, or number of customers expands in both directions, it will be necessary to establish a formal definition. This discussion is particularly informed by how it is used by the UNEP (United Nations Environment Program, Dean Cooper, 2015). As used here, a minigrid **is** a utility grid; it is an electricity distribution system with one

[3] The term "minigrid" is not hyphenated here for consistency with the other terms. This paper makes no recommendation on whether it should be in general.

entity that provides power, to customers that purchase it. The direct utility link reflects the fact that one potential outcome of (AC) minigrid operation is the attraction of greater customer numbers and ultimate connection to the existing national grid structure. The following additional characteristics generally apply to what is, or is not, a minigrid.

- There may be a minimum and/or maximum number of customers.
- There may be a minimum and/or maximum peak electrical capacity.
- There may be a maximum geographical extent.
- Providing power should be a primary or significant activity of the providing entity.
- While power flow from customers to the minigrid may occur, flow from the minigrid to customers should be significantly greater.

Additional notes on minigrids are as follows:

- Exchange of power among adjacent buildings without a clear central entity would not constitute a minigrid. This would be a network of nanogrids or microgrids.
- A minigrid might be all AC, all DC, or a combination of the two.
- There should be no requirements or limits on voltages, though with an upper bound on electrical capacity, there are limits to the voltages that might ever make sense.

4 Other Sources and Terms

4.1 **Smart grid *or* intelligent grid** IEC Electropedia (IEC, 2015)

"electric power system that utilizes information exchange and control technologies, distributed computing and associated sensors and actuators, for purposes such as:

"– to integrate the behavior and actions of the network users and other stakeholders,

"– to efficiently deliver sustainable, economic and secure electricity supplies"

Any micro- or nanogrid could meet this definition if it includes communication.

4.2 **Island** (in an electric power system) IEC Electropedia (IEC, 2015)

"part of an electric power system, that is disconnected from the remainder of the interconnected system, but remains energized

"Note – An island can be either the result of the action of automatic protections or the result of a deliberate action."

4.3 Small scale embedded generator or micro-generator or SSEG (abbreviation) (IEC, 2015)

Source of electric energy and all associated interface equipment able to be connected to a regular electric circuit in a low-voltage electrical installation and designed to operate in parallel with a public low-voltage distribution network

Note – Typically, a SSEG is connected at low voltage and rated up to and including 16 A per phase.

The IEC Electropedia does not define microgrid or the other terms used in this paper.

The IEEE Dictionary (IEEE, 2000) defines grid, from a hydroelectric standard, as

"Network, usually of a power company, for transmitting and distributing electrical power."

The dictionary does not define microgrid, and only mentions power distribution in the specific context of underground cables.

The term "low voltage" has a variety of very different meanings depending on context, from less than 60 V to well over 1,000 V. This brings up the undesirability of using terms like this (e.g., "small") in definitions because they lack a clear quantitative meaning.

5 Implications for Technology and Policy

Local grids can and do exist as individual entities (connected to a utility grid or not), but are even more useful when connected (networked) to each other. Microgrids in adjacent buildings could have the ability to be connected to each other separately from how they might be on a common section of a utility grid, in order to exchange power over the direct path when the utility grid is operating or not (this is known as the "over-the-fence" rule[4]). Similarly, nanogrids can be networked to each other, and always need to be, as the LPD definition specifies that local generation forms its own nanogrid, so would be networked to at least one additional nanogrid that has end-use devices (and likely storage internal to the controller).

The selection of particular definitions is entangled with a set of questions about how local grids relate to the utility grid (if present), and utility meter.

- Should a microgrid operate internally only when islanded from a utility grid, and otherwise have the building be a typical part of the utility grid? Or should microgrid operations be continuous, managing supply and demand, and actively managing the exchange of power with a utility grid?

[4] Tim Lindl, *Letting Solar Shine: An Argument to Temper the over-the-Fence Rule*, 36 Ecology L.Q. (2009). Available at: http://scholarship.law.berkeley.edu/elq/vol36/iss4/3

- Should a utility grid have visibility to inside the microgrid, and interact with component devices directly, or only interface with a single device, the microgrid controller?
- Under what circumstances should adjacent grids be tightly coupled to each other? (alternative is to be only loosely coupled; AC systems generally are tightly coupled, while DC systems, particularly when they incorporate batteries, are often loosely coupled.)

6 Summary

The definitions recommended here, particularly the identified definition of nanogrid, and adapted definition of microgrid, should be used in grid discussions. Some standards organization should take on the topic of grid definitions, for the goal of fostering clarity of communication.

The key defining aspect of a microgrid is **capability**; for a picogrid it is **singularity**; for a nanogrid, **simplicity**. These three definitions are all compatible and complementary; they do not exist on a scale of differential sizes as the metric prefixes suggest[5].

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[10] Nordman, Bruce, Ken Christensen, and Alan Meier, “Think Globally, Distribute Power Locally,” IEEE Computer (Green IT Column), September 2012.

[5] Such usage is not unique here, as with “microfinance”, “microcomputer”, “microbrew”, “micro drone”, etc.

[11] Nordman, Bruce, and Ken Christensen, "DC Local Power Distribution with Microgrids and Nanogrids," First International Conference on DC Microgrids, Atlanta, GA, June 2015.

[12] Nordman, Bruce, and Ken Christensen, "The Need for Communications to Enable DC Power to be Successful," First International Conference on DC Microgrids, Atlanta, GA, June 2015.